

# A First Measurement of the Tensor-Polarized Structure Function $b_1^d$

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**Abstract.** The HERMES experiment studies the spin structure of the nucleon using the 27.6 GeV longitudinally polarized positron beam of HERA and an internal target of pure gases. In addition to the well-known spin structure function  $g_1$ , measured precisely with longitudinally polarized proton and deuteron targets, the use of a tensor-polarized deuteron target provides access to the tensor polarized structure function  $b_1^d$ . The latter, measured with an unpolarized beam, quantifies the dependence of the parton momentum distribution on the nucleon spin. HERMES had a 1-month dedicated run with a tensor polarized deuterium target during the 2000 data taking period. Here preliminary results on the tensor-polarized structure function  $b_1^d$  are presented for the kinematic range  $0.002 < x < 0.85$  and  $0.1 \text{ GeV}^2 < Q^2 < 20 \text{ GeV}^2$ .

## INTRODUCTION

The HERMES experiment [1] has been designed to measure the nucleon spin structure functions from deep inelastic scattering (DIS) of polarized positrons and electrons from polarized gaseous targets (H, D,  $^3\text{He}$ ). Three of the main leading-twist structure functions are listed in the table below, along with their interpretation in the Quark-Parton Model. The sums are over quark and antiquark flavours  $q$  and the dependences on  $Q^2$  and Bjorken  $x$  are omitted for simplicity:

	Proton	Deuteron
$F_1$	$\frac{1}{2} \sum_q e_q^2 [q^+ + q^-]$	$\frac{1}{3} \sum_q e_q^2 [q^+ + q^- + q^0]$
$g_1$	$\frac{1}{2} \sum_q e_q^2 [q^+ - q^-]$	$\frac{1}{2} \sum_q e_q^2 [q^+ - q^-]$
$b_1$	--	$\frac{1}{2} \sum_q e_q^2 [2q^0 - (q^- + q^+)]$

The unpolarized structure function  $F_1$  measures the quark momentum distribution summed over all the possible helicity states. The polarized structure function  $g_1$  is sensitive to the spin structure of the nucleon, and measures the imbalance of quarks with the same ( $q^+$ ) or opposite ( $q^-$ ) helicity with respect to the nucleon they belong to. For targets of spin 1 such as the deuteron, the tensor structure function  $b_1$  compares the quark momentum distribution between the zero-helicity state of the hadron ( $q^0$ ) and the average of the helicity-1 states ( $q^+ + q^-$ ). As the deuteron is a weakly-bound state of spin-half nucleons,  $b_1^d$  was initially predicted to be small [2]. More recently, coherent double scattering models have predicted a sizable  $b_1^d$  at low  $x$  [3, 4, 5], violating the sum rule which suggests a vanishing first moment of  $b_1^d$  [6]. Although  $b_1^d$  describes basic

properties of the spin-1 deuterium nucleus, and may affect the experimental determination of  $g_1^d$ , it has not yet been measured. In 2000, HERMES collected a dedicated data set with a tensor polarized deuterium target for the purpose of making a first measurement of  $b_1^d$ . Preliminary results from these data are presented in this paper.

## HERMES SETUP

The HERMES experiment is installed in the HERA ring where the beam positrons self-polarize by emission of synchrotron radiation (Sokolov-Ternov effect) along the direction of the bending magnetic field. Longitudinal beam polarization, needed for the  $g_1^d$  measurement, is obtained with two spin rotators placed immediately upstream and downstream of the HERMES apparatus. As  $b_1^d$  appears in the symmetric part of the hadronic tensor [2], its measurement neither depends on the beam polarization nor is diluted by the depolarization of the virtual photon. At HERMES, an “unpolarized beam” is achieved by grouping together data with opposite beam polarization.

A unique feature of the HERMES experiment is its tensor-polarizable gaseous target [7]. Deuterium has a total of six hyperfine states depending on the relative orientation of the electron and nuclear spins. An atomic beam source (ABS) generates a Deuterium atomic beam and selects the two hyperfine states with the desired nuclear polarization. A cylindrical 40 cm long,  $75\mu\text{m}$  thick Al tube (target cell) confines the polarized gas along the positron beam line, where a longitudinal magnetic field provides the quantization axis for the nuclear spin. Every 90 seconds, a diagnostic system measures the atomic and molecular abundances and the atomic polarization inside the cell, then the polarization of the injected gas is changed. The vector  $V$  and tensor  $T$  atomic polarizations are

$$V = \frac{n^+ - n^-}{n^+ + n^- + n^0} \quad T = \frac{n^+ + n^- - 2n^0}{n^+ + n^- + n^0}, \quad (1)$$

where  $n^+$ ,  $n^-$ ,  $n^0$  are the atomic populations inside the cell with positive, negative and zero spin projection onto the beam axis. In 2000 the running conditions were very stable, the recombination on the cell surface was negligible, and no correction was needed for the residual polarization of the recombined atoms. An average tensor polarization greater than 80 % was obtained with a residual vector polarization of only 1 %. In contrast to the solid targets used by other experiments, the HERMES target does not suffer from radiation damage thanks to the continuous flow of the target gas. Its polarization can be continuously measured, rapidly reversed, and is not diluted by non-polarizable material.

The HERMES detector is a forward spectrometer with a dipole magnet providing a field integral of 1.3 T·m. A horizontal iron plate shields the HERA beam lines from the field, thus dividing the spectrometer into two identical halves with a minimum vertical acceptance of  $\pm 40$  mrad. The acceptance extends to  $\pm 140$  mrad vertically and to  $\pm 170$  mrad horizontally. In this analysis 36 drift chamber planes in each detector half were used for tracking. Positron identification is accomplished using a probability method based on signals of three subsystems: a lead-glass block calorimeter, a transition-radiation detector, and a preshower hodoscope. For positrons in the momentum range of 2.5 to 27 GeV, the identification efficiency exceeds 98 % with a negligible hadron contamination, the average polar angle resolution is 0.6 mrad, and the average momentum resolution is 1 – 2 %.

## MEASUREMENT

Depending on the beam ( $P_B$ ) and target ( $V$  and  $T$ ) polarizations, the lepton-nucleon DIS cross section measured by the experiment is sensitive to the vector  $A_1$  ( $A_2$  is here neglected) and tensor  $A_{zz}$  asymmetries of the virtual photon nucleon cross section

$$\sigma_{\text{meas}} = \sigma_U \left[ 1 + P_B D_\gamma V A_1 + \frac{1}{2} T A_{zz} \right] \quad \begin{array}{ccc} P_B & V & T \\ \sigma^+ & 1 & 1 & 1 \\ \sigma^- & 1 & -1 & 1 \\ \sigma^0 & 0 & 0 & -2 \end{array} \quad (2)$$

$\sigma_U$  is the unpolarized cross section  $(\sigma^+ + \sigma^- + \sigma^0)/3$  and  $D_\gamma$  is polarization transfer from the lepton beam to the virtual photon. Here and in the following no higher-twist contribution ( $g_2, b_3, b_4$ ) is considered. The vector asymmetry  $A_1$  is related to  $g_1^d$ ; it is measured with a polarized beam ( $P_B = 1$ ) by comparing the cross sections for a target with the same  $\sigma^+$  and opposite  $\sigma^-$  helicity as the beam:

$$A_1 = \frac{\sigma^+ - \sigma^-}{2\sigma_U D_\gamma} = \frac{g_1}{F_1} = A_1^{\text{meas}} \left[ 1 + \frac{1}{2} T A_{zz} \right]. \quad (3)$$

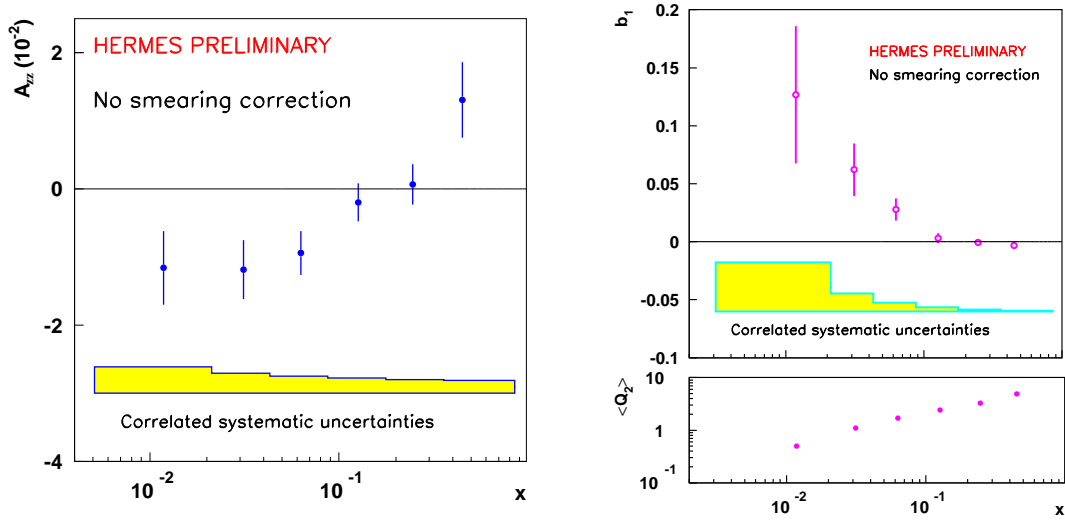
Here  $A_1^{\text{meas}}$  is the asymmetry typically measured by experiments, where  $(\sigma^+ + \sigma^-)/2$  is used rather than  $\sigma_U$ . The tensor term, until now neglected in  $g_1^d$  measurements, is needed to ensure that the denominator is proportional to  $\sigma_U$  and so to  $F_1$ . The tensor asymmetry  $A_{zz}$ , and the related  $b_1^d$ , provide the missing information on the difference between the cross section for the zero-helicity target state and the spin-averaged states of helicity 1:

$$A_{zz} = \frac{(\sigma^+ + \sigma^-) - 2\sigma^0}{3\sigma_U} = -\frac{2b_1}{3F_1}. \quad (4)$$

At HERMES, the target residual vector polarization in the  $\sigma^0$  case and in the case of the sum  $\sigma^+ + \sigma^-$  is very small and has a negligible effect on the  $A_{zz}$  measurement. The vector contribution is further reduced by combining together data with opposite beam helicities. The kinematic range accessible for the  $b_1^d$  measurement is limited to the intervals  $0.002 < x < 0.85$  and  $0.1 < y < 0.91$  due to detector acceptance, resolution, and trigger requirements. Inclusive deep-inelastic events are selected by the requirements:  $Q^2 > 0.1 \text{ GeV}^2$  and  $W^2 > 3.24 \text{ GeV}^2$ . The total  $x$ -range is divided into 6 bins. For each  $x$ -bin the following yield asymmetry is calculated:

$$A_{zz} = \frac{1}{T} \cdot \left[ \frac{(N/L)^+ + (N/L)^- - 2 \cdot (N/L)^0}{(N/L)^+ + (N/L)^- + (N/L)^0} \right]. \quad (5)$$

The numbers of events selected ( $N$ ) are corrected per spin state for the background arising from charge symmetric processes. The corresponding luminosities ( $L$ ) used for normalization are measured from Bhabha scattering off the target gas electrons. The radiative corrections on  $A_{zz}$  are calculated using POLRAD [8]. For this preliminary result the DIS radiative tail is neglected due to the small size of  $A_{zz}$  and the elastic radiative tail is estimated from a not fully updated parameterization of the deuteron quadrupole

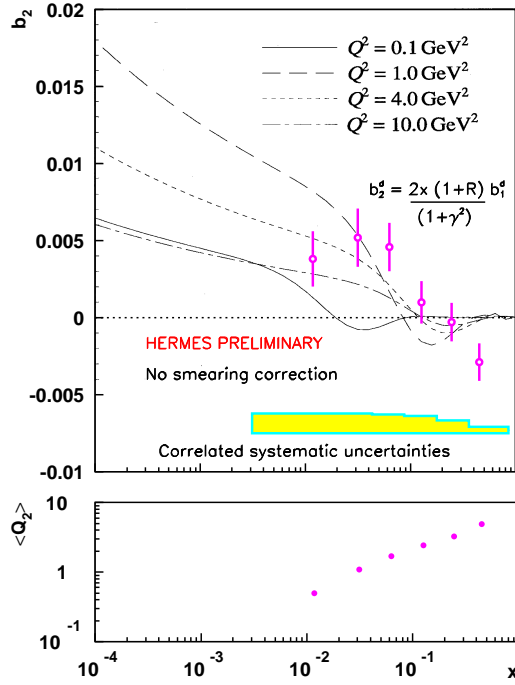


**FIGURE 1.** The tensor asymmetry  $A_{zz}$  (left) and the tensor-polarized structure function  $b_1^d$  (right) as measured by HERMES. The error bars are statistical only and the shaded bands show the estimated systematic uncertainties. The bottom panel on the right plot shows the average  $Q^2$  of the measurements.

form factor [9]. The statistical error was enlarged by almost a factor of 2 at low  $x$  to account for radiative background. The measured  $A_{zz}$  is presented in Fig. 1. The systematic uncertainties are correlated over the kinematical bins, being dominated by the target density normalization between different injection modes of the ABS. The target polarization measurement, the misalignment of the spectrometer, and the hadron contamination give negligible systematic effects. Data with different beam polarizations were checked to give compatible  $A_{zz}$  results. No systematic error has been estimated from the still incomplete radiative correction.  $A_{zz}$  is found to be less than 2 %. From this result, the influence of the tensor asymmetry bias on a  $g_1^d$  measurement is estimated to be less than 0.5 – 1.0 %.

The spin structure function  $b_1^d$  is extracted from the tensor asymmetry via the relation  $b_1^d = -\frac{3}{2}A_{zz} \frac{(1+\gamma^2)F_2^d}{2x(1+R)}$ , where the structure function  $F_1^d$  has been expressed in terms of the ratio  $R = \sigma_L/\sigma_T$  [10] and the structure function  $F_2^d$  ( $\gamma$  is a kinematic factor).  $F_2^d = F_2^p(1 + F_2^n/F_2^p)/2$  is calculated using parameterizations for  $F_2^p$  [11] and  $F_2^n/F_2^p$  [12]. Fig. 1 displays the result for  $b_1^d$ , which is small but different from zero. The structure function  $b_2^d$  has also been extracted, using the Callan-Gross relation  $b_2^d = \frac{2x(1+R)}{(1+\gamma^2)}b_1^d$ . The data indicate a rise at low  $x$  as predicted by the most recent theoretical models [3, 4, 5]. A comparison of the measured  $b_2^d$  with the prediction of one of the models [5] is given in Fig. 2.

In conclusion HERMES has provided the first direct measurement of the structure function  $b_1^d$  in the kinematic range  $0.002 < x < 0.85$  and  $0.1 \text{ GeV}^2 < Q^2 < 20 \text{ GeV}^2$ . The preliminary result for the tensor asymmetry is sufficiently small to produce an effect of



**FIGURE 2.** The tensor-polarized structure function  $b_2^d$ . The error bars are statistical only and the shaded bands show the estimated systematic uncertainties. The bottom panel shows the average  $Q^2$  of the measurements. The curves are from calculations within the re-scattering model of Ref. [5] for  $Q^2$  values in the range of the HERMES measurement.

less than 1 % on the measurement of  $g_1^d$ . The dependence of  $b_1^d$  on Bjorken  $x$  is in qualitative agreement with expectations based on coherent double scattering models [3, 4, 5] and favors a sizeable  $b_1^d$  at low- $x$ . This suggests a significant tensor polarization of the sea-quarks, violating the Close-Kumano sum rule [6]. This observation is analogous to the well-established  $\bar{u} - \bar{d}$  asymmetry of the sea and the consequent violation of the Gottfried sum rule [13].

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